GSFC · 2015

Environmental Simulation of a Spacecraft on a Launchpad

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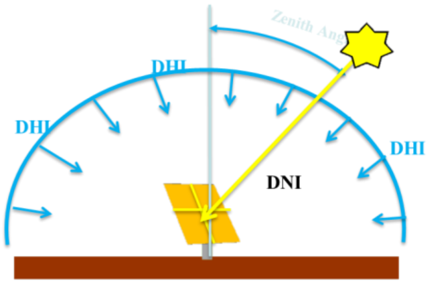
Introduction

- Present an example model of a Falcon 9 rocket with a spacecraft on the launch pad
- Show a method for realistic modeling of the weather effects and solar loads on aerospace hardware at any time, date and location on the earth
- MSC Patran, Sinda and Thermica was used in the example model
- Other thermal analyzers and orbital heating codes could be used, but would require some manual work to incorporate the data from the Department of Energy weather files into the model. This is done automatically with Environment Simulation Module that is part of MSC Patran 2013 or later.

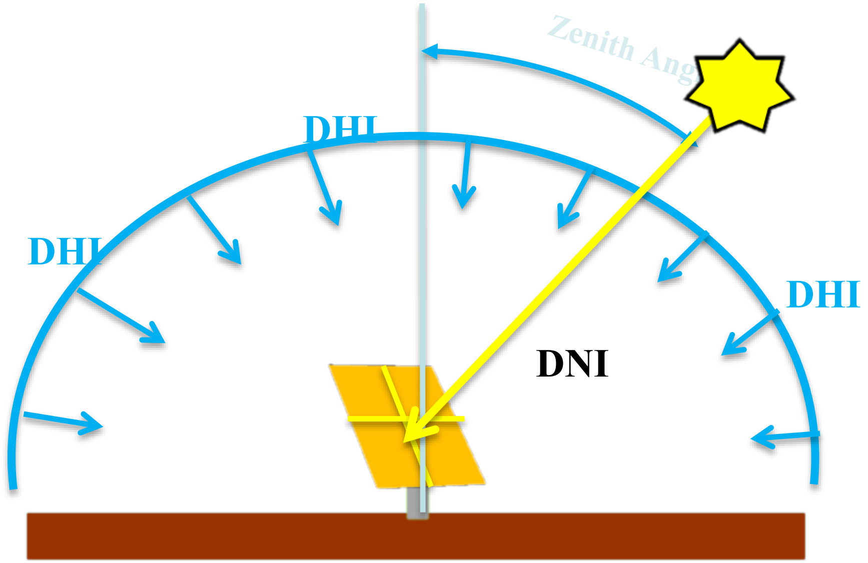


Solar Energy 101

Solar Energy Fundamentals

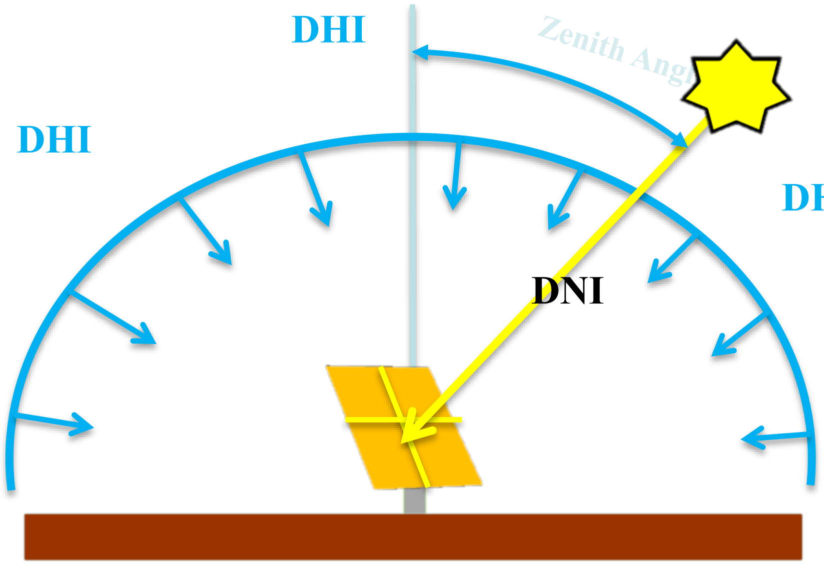
DNI and DHI

- DNI (direct normal irradiance)
  - This is the directional component, the beam component
- DHI (diffuse horizontal irradiance)
  - This part comes from the entire sky, due to scattering in the atmosphere



GHI

- GHI (Global Horizontal Irradiance)
  - GHI is a sum of the DNI and DHI according to:
  - GHI = DHI + DNI * cos (Z)
    - Where Z is the angle from the normal of the earth to the Sun

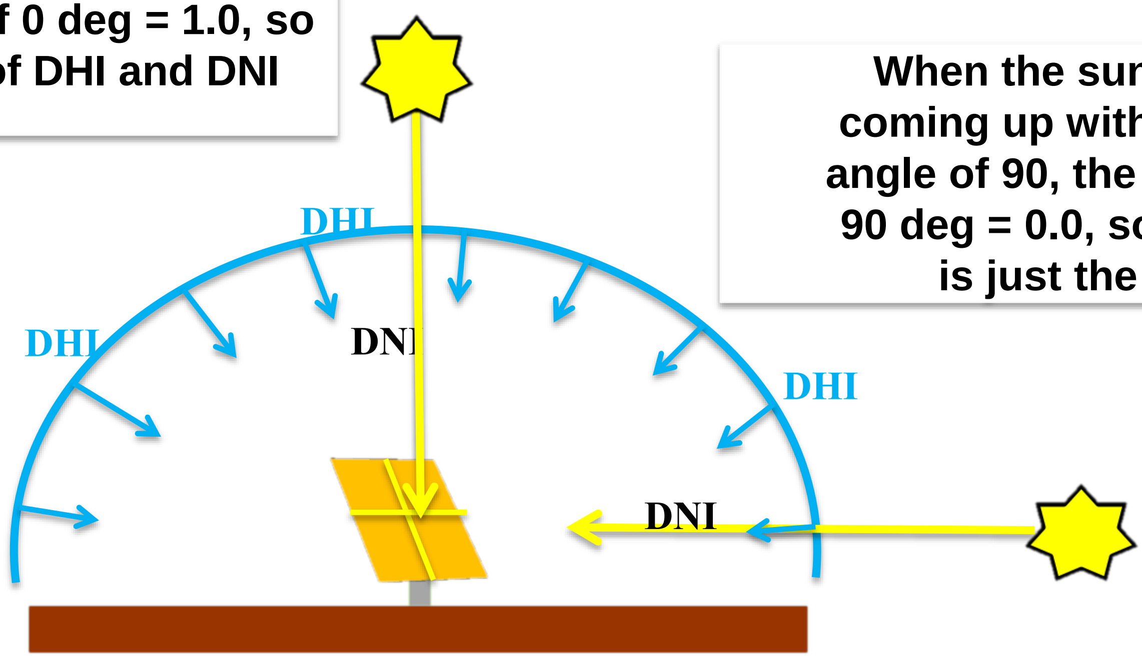


GHI for Different Zenith Angles

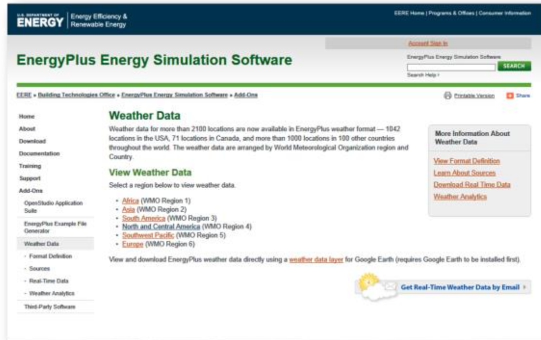
- GHI = DHI + DNI * cos (Z)

  Where Z is the angle from the normal of the earth to the Sun

When the sun is directly overhead with a zenith angle of zero, the cosine of 0 deg = 1.0, so GHI is the sum of DHI and DNI



When the sun is just coming up with a zenith angle of 90, the cosine of 90 deg = 0.0, so the GHI is just the DHI



Weather Data

What is TMY3 data and why do I need it!

Typical Meteorological Year (TMY)

A typical meteorological year (TMY) data set provides designers with the following:

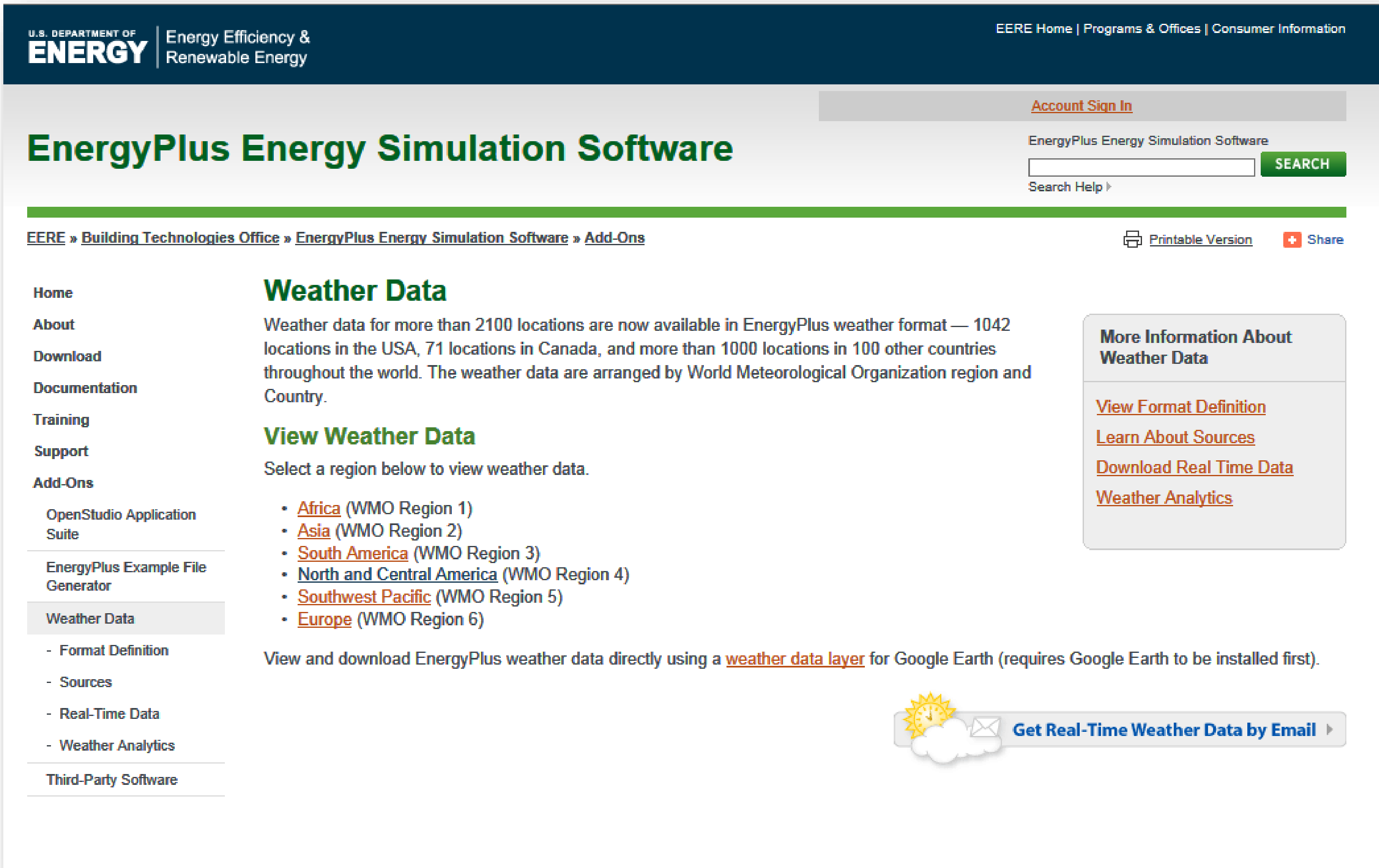
- A reasonably sized annual (1 year) set of data
- Hourly meteorological values that typify conditions at a specific location. This data includes DHI, DNI, GHI, air temperature/humidity deep ground temperature and much more.
- Averaged over a long period of time, such as 30 years to give typical values
- Their intended use is for computer simulations of solar energy conversion systems and building systems to facilitate performance comparisons of different system types, configurations, and locations in the United States and its territories.
- Not designed to provide meteorological extremes but represents a year of typical climatic conditions for a location.

TMY3 Data

- TMY3 is the latest version of the TMY data updated in 2008.
- EPW – Energy Plus Weather (EPW) contain data from over 2000 locations around the world. TMY3 is the US standard. Other countries use different formats but are all saved in a EPW format and contain similar data.
- Because TMY3 data sets represent typical rather than extreme conditions, they are not suited for designing systems to meet the worst-case conditions occurring at a location. The Design Day feature in our software products is used for these worst-case conditions.
- Environment Simulation Module (ESM) in Patran directly reads the EPW files and computes or extracts data that is written automatically into Patran for use in thermal models.
- For those who don't have Patran, downloadable readers that can access the data from EPW files are available on the web site along with the data which can be manually entered into other software.

Department of Energy Weather Database

Search for keywords EPW weather data



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    - Weather Analytics
  - Third-Party Software

Weather Data

Weather data for more than 2100 locations are now available in EnergyPlus weather format — 1042 locations in the USA, 71 locations in Canada, and more than 1000 locations in 100 other countries throughout the world. The weather data are arranged by World Meteorological Organization region and Country.

View Weather Data

Select a region below to view weather data.

- Africa (WMO Region 1)
- Asia (WMO Region 2)
- South America (WMO Region 3)
- North and Central America (WMO Region 4)
- Southwest Pacific (WMO Region 5)
- Europe (WMO Region 6)

View and download EnergyPlus weather data directly using a weather data layer for Google Earth (requires Google Earth to be installed first).

More Information About Weather Data

- View Format Definition
- Learn About Sources
- Download Real Time Data
- Weather Analytics

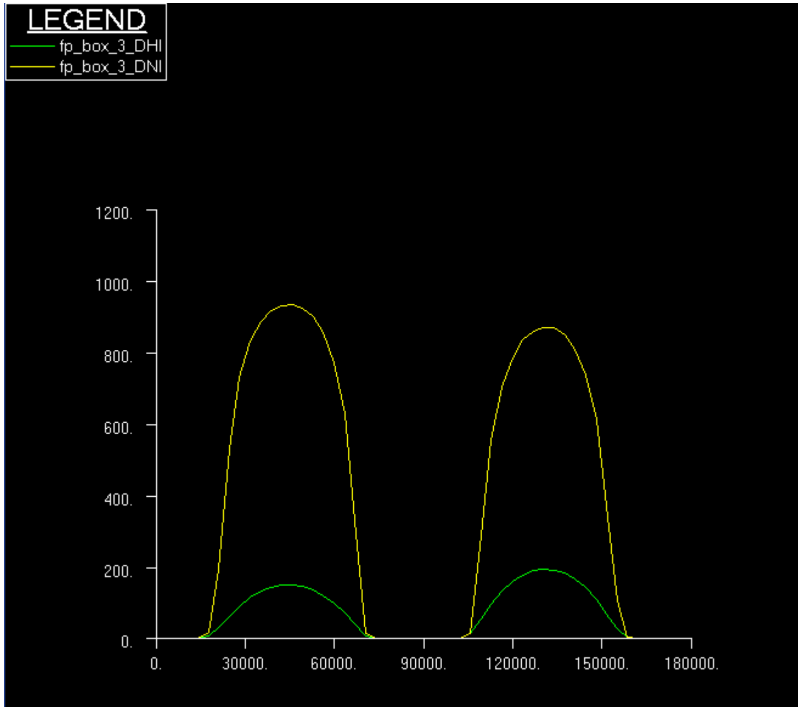
Get Real-Time Weather Data by Email

DNI and DHI for Two Locations on May 15,16

Phoenix Arizona

DNI 950w/sqm

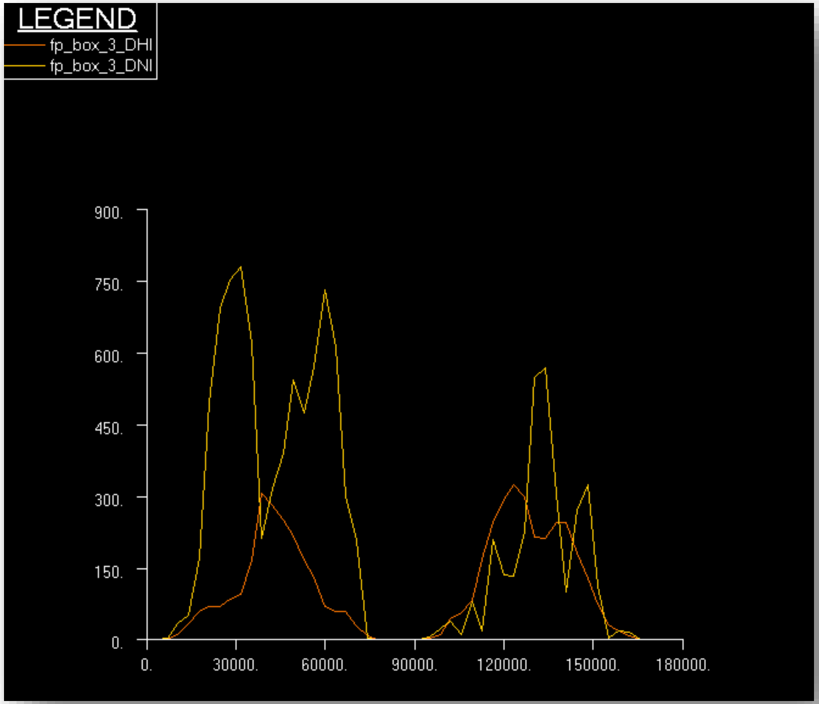
DHI 150w/sqm



Fairbanks Alaska

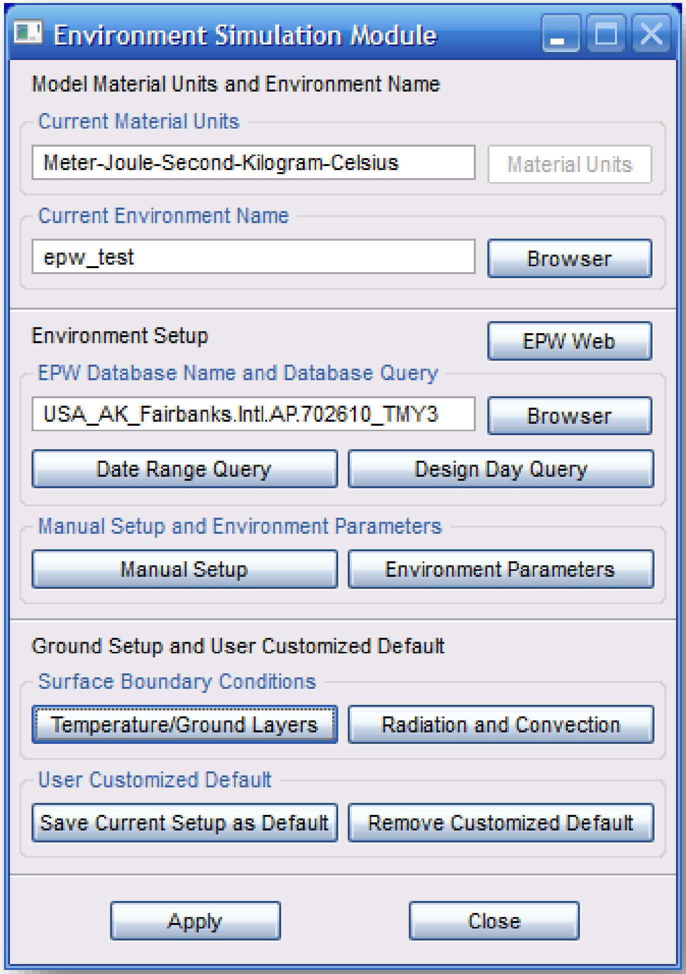
DNI 750w/sqm

DHI 300w/sqm



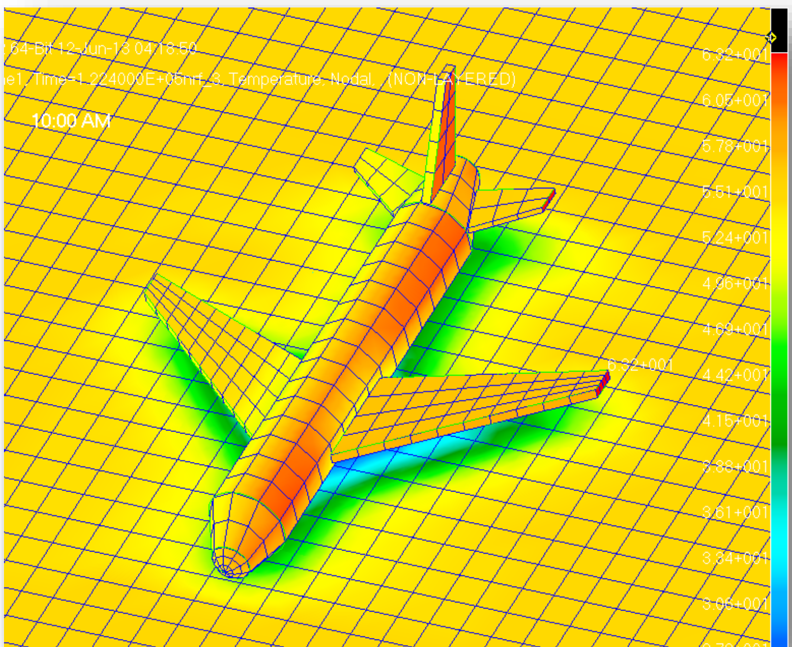
Methods for Using Weather Data

- Hourly Query - Pick a Day or range of days and the start and finish hour
- Design Day Query - Create worst case weather based on the users criteria
- Manually Setup – Use any tables desired using data from sources such as Mil Handbook 310

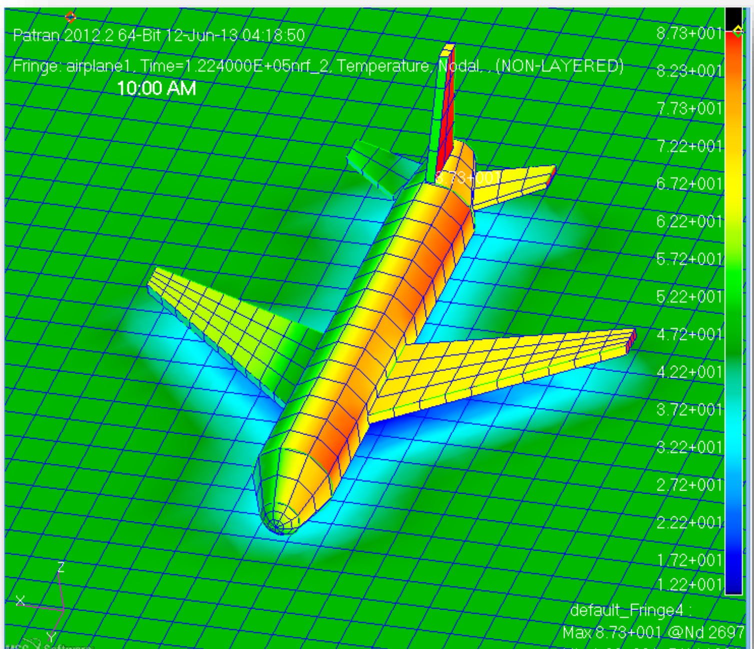


Comparison Max DNI to Max DHI at 10AM

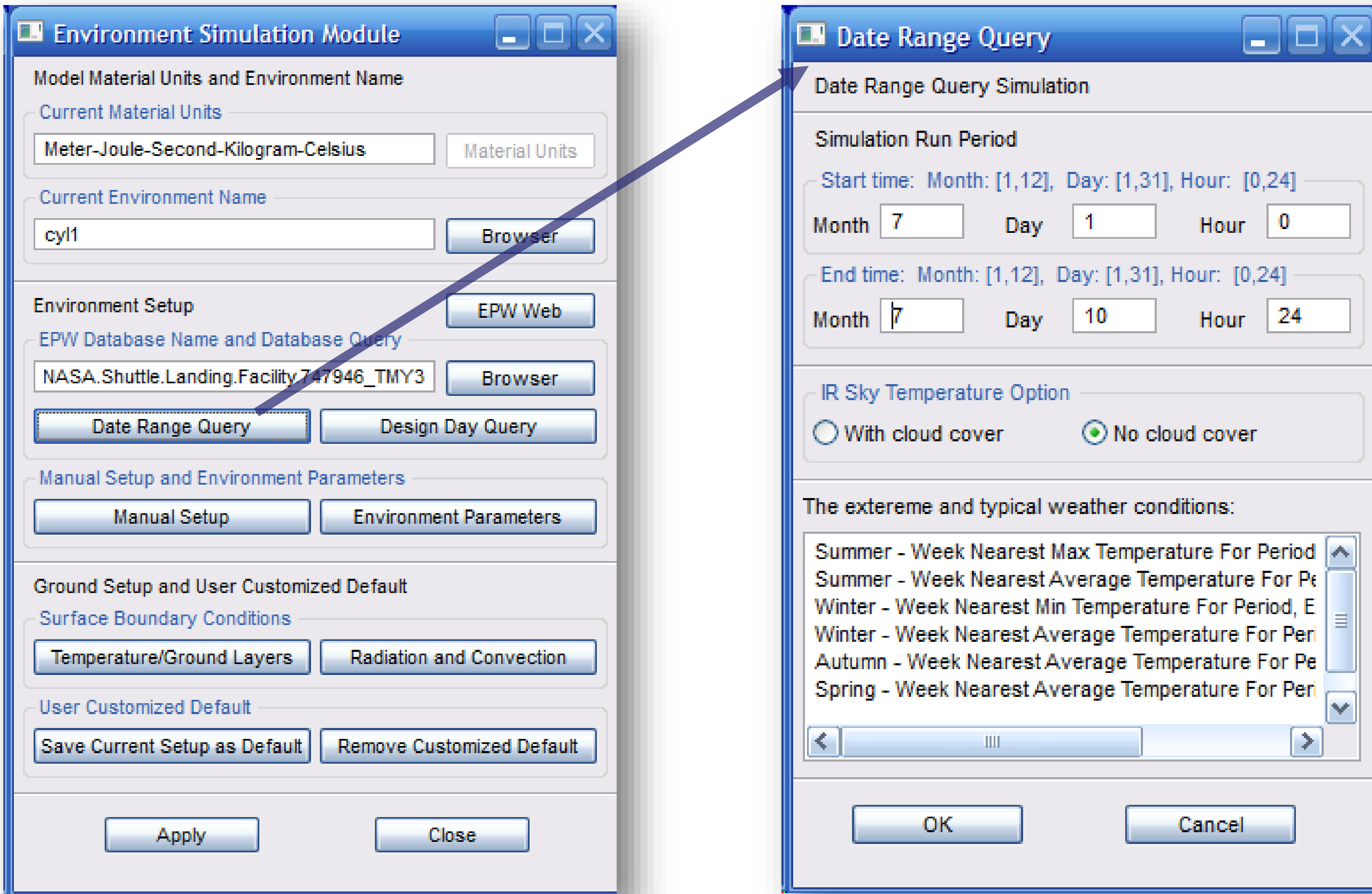
Max DHI
Diffuse Horizontal Irradiance
27.9 °C to 63.2 °C



Max DNI
Direct Normal Irradiance
12.2 °C to 87.3 °C

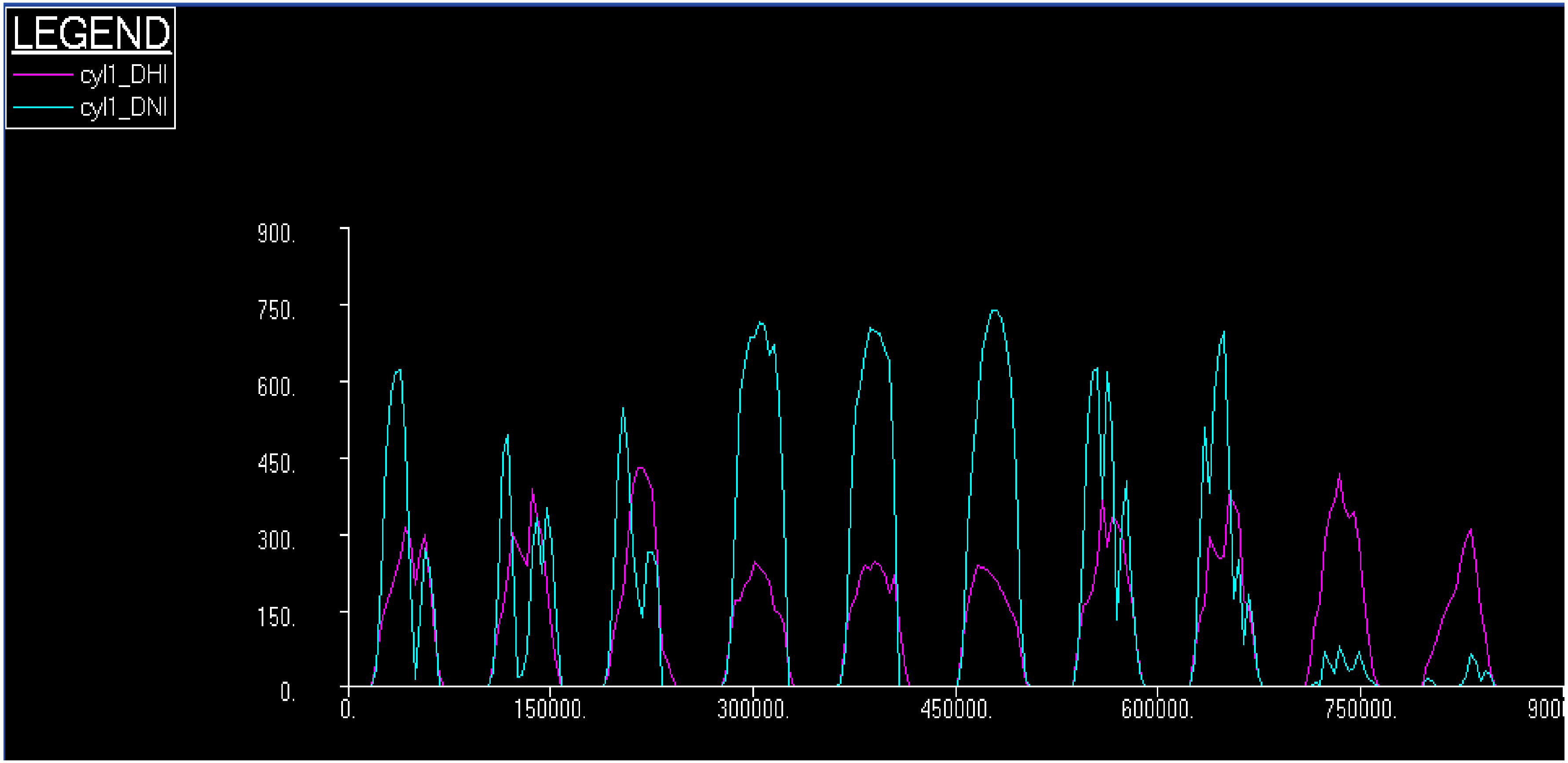


Date Range Query July 1-10

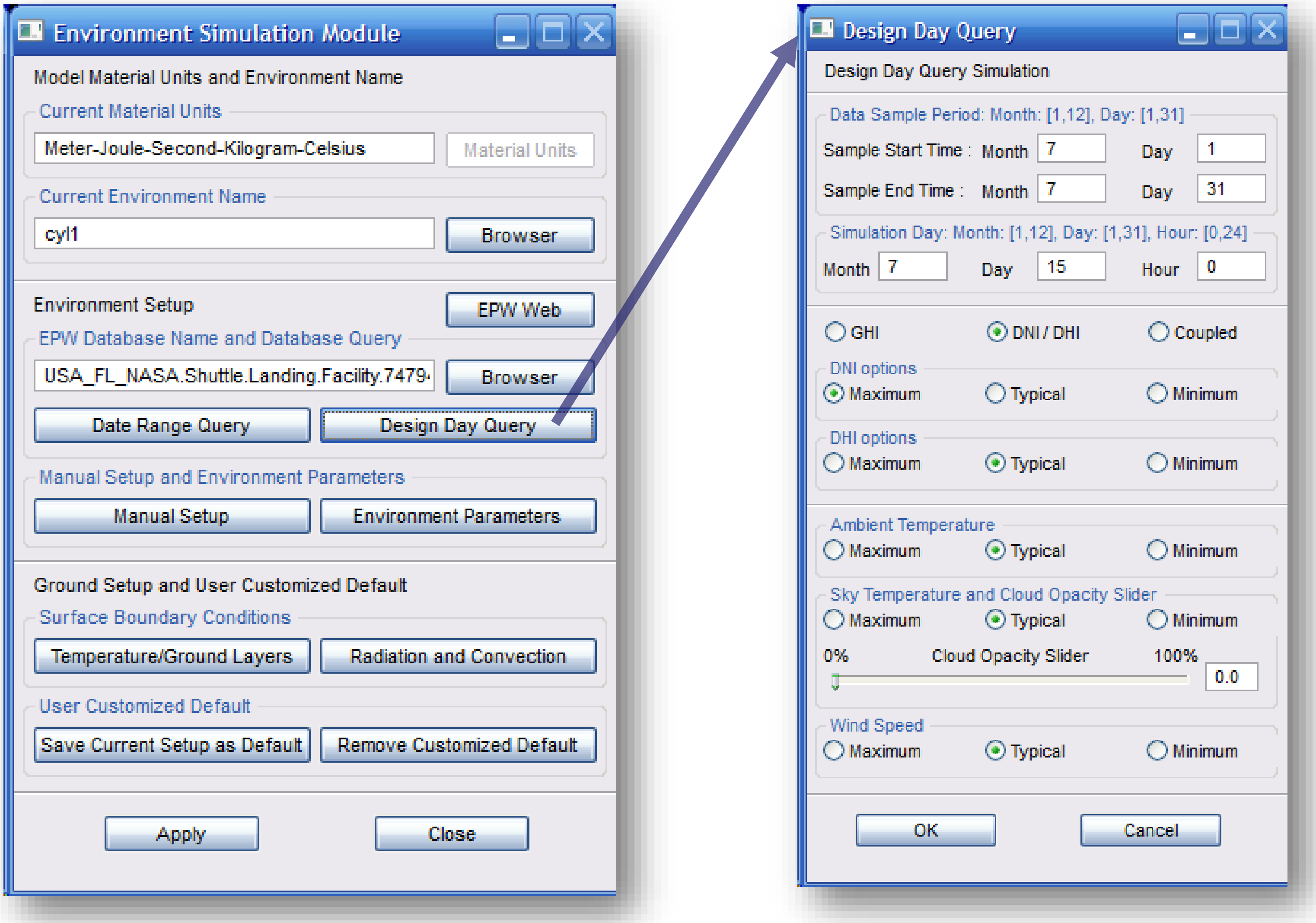


Date Range Query July 1-10

KSC's Shuttle Landing Facility
DHI and DNI Plot for 10 Days

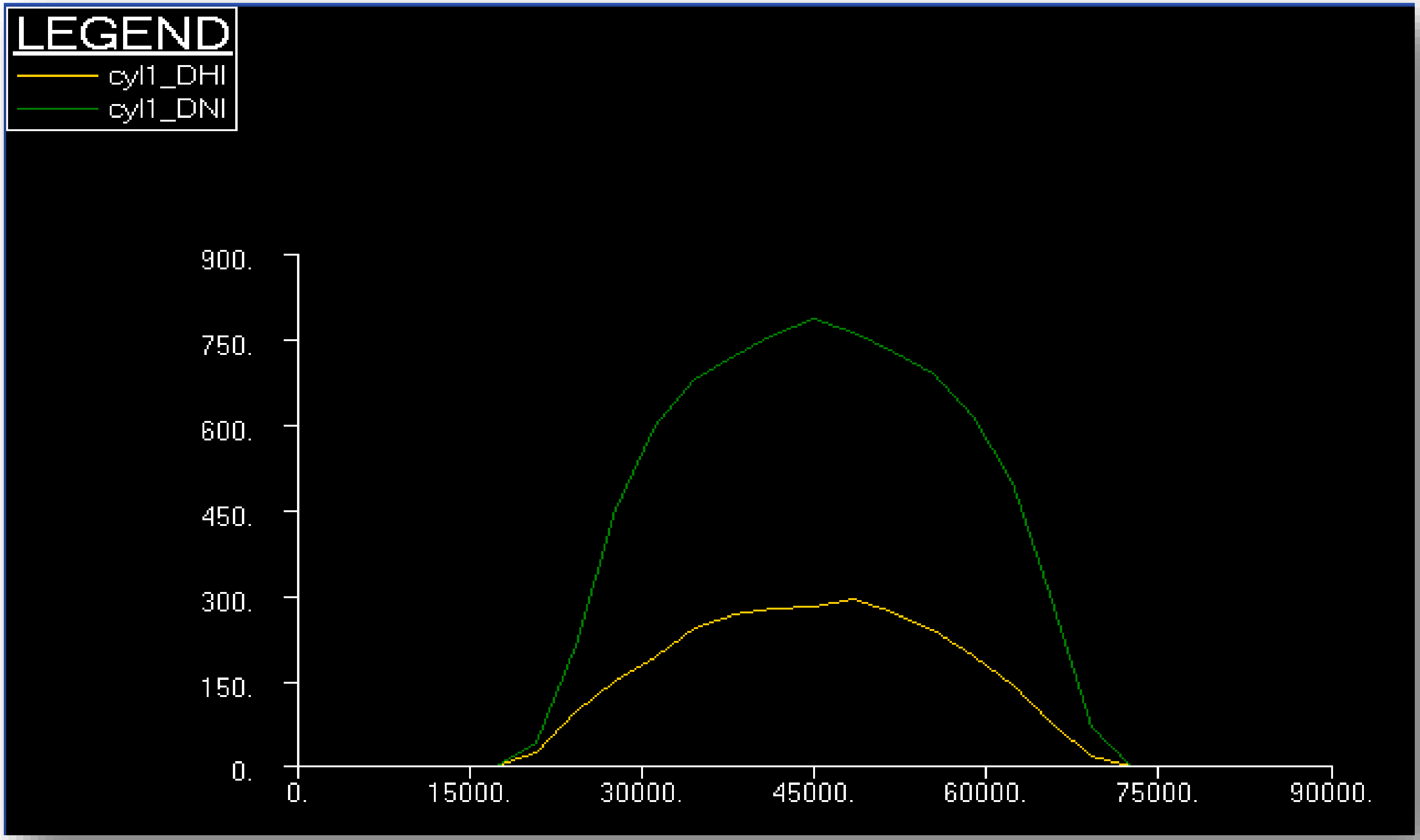


Design Day Query – July 1-31

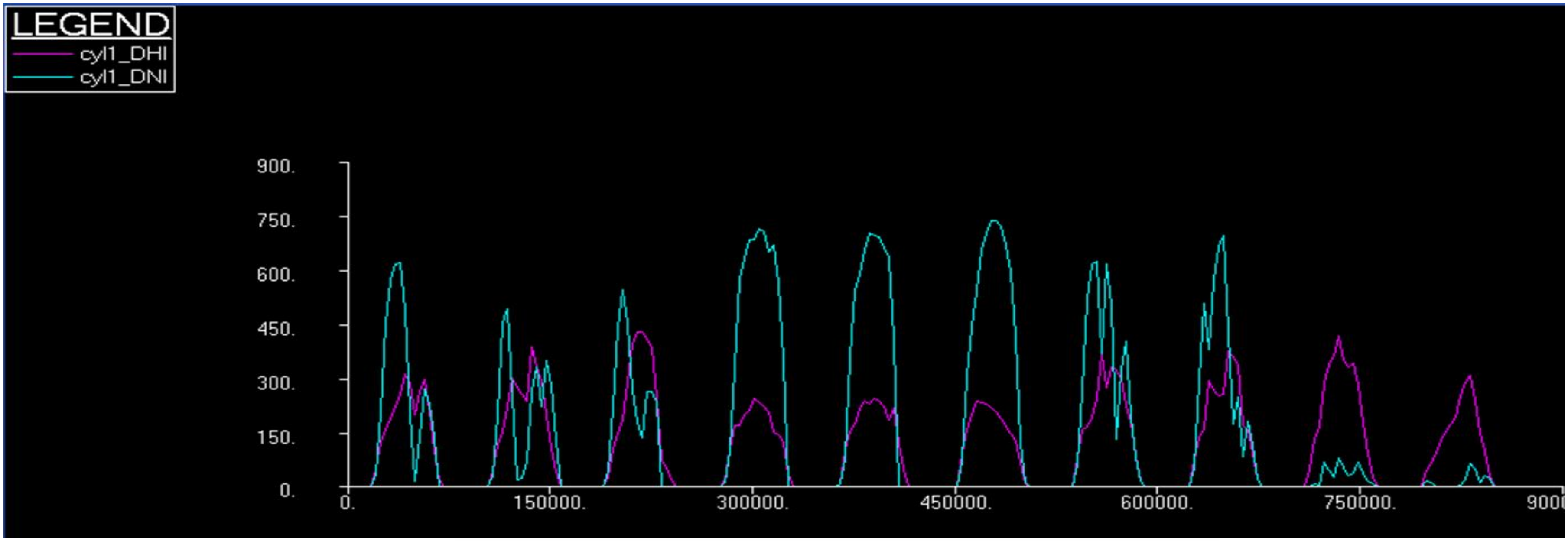


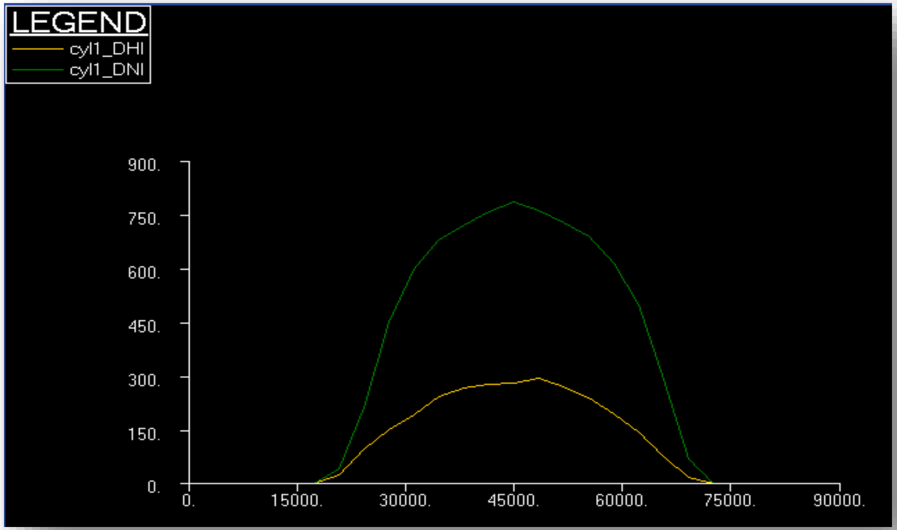
Design Day Query – July 1-31

KSC's Shuttle Landing Facility
DHI and DNI Plot for Design Day



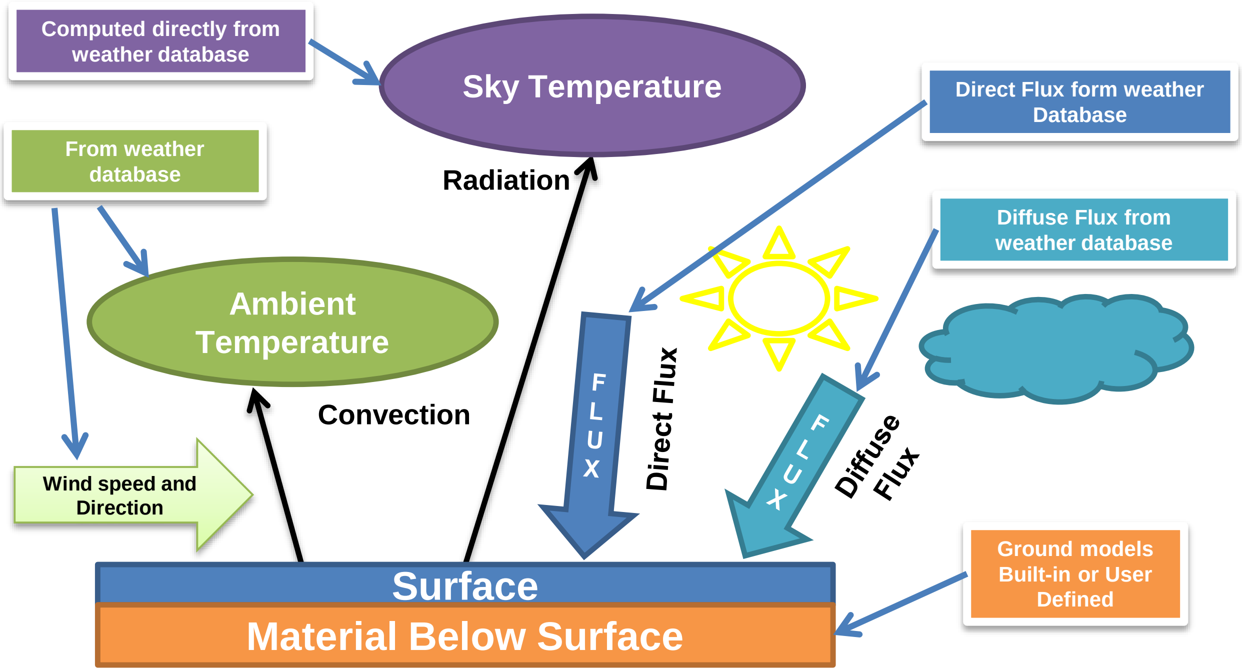
Design Day to Date Range Query

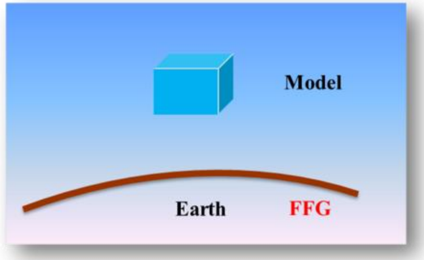


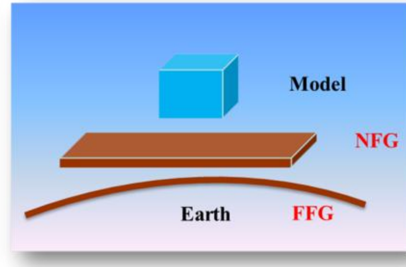


Environment Simulation Loads

The following data is read from the weather and is transient hourly data







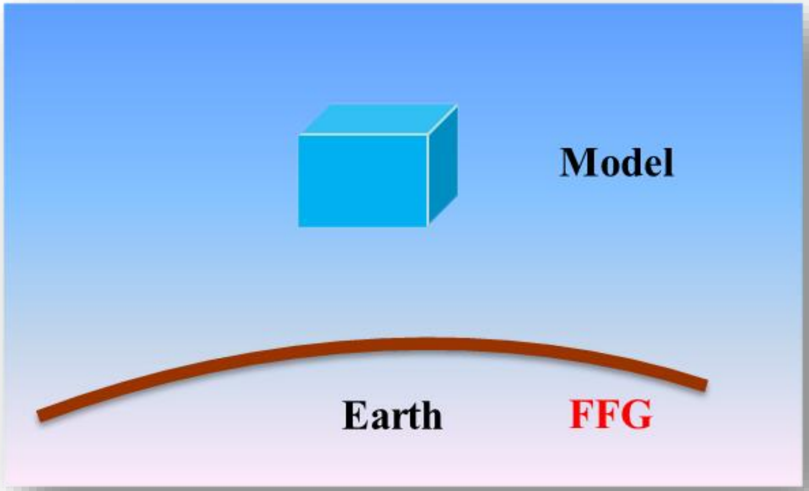
Ground Models

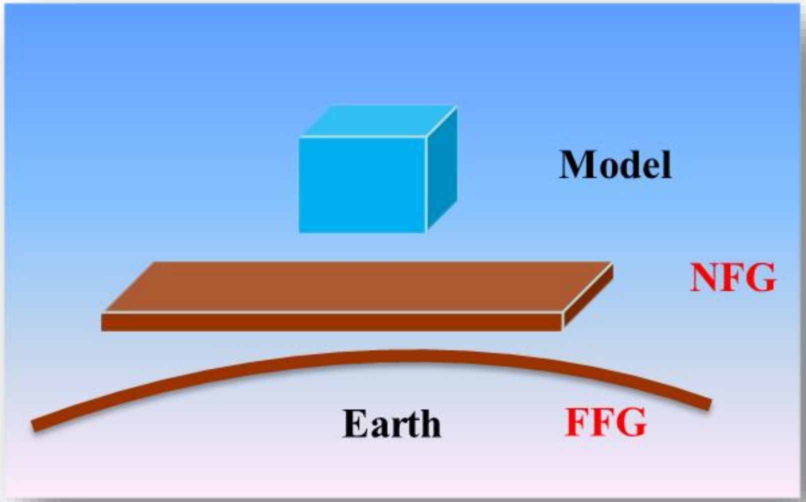
Far Field Ground (FFG) and Near Field Ground (NFG) Models

Ground Modeling

When creating a thermal model using the Environment Simulation Module (ESM) feature in Patran, the ground needs to be considered. Two types of ground models can be used.

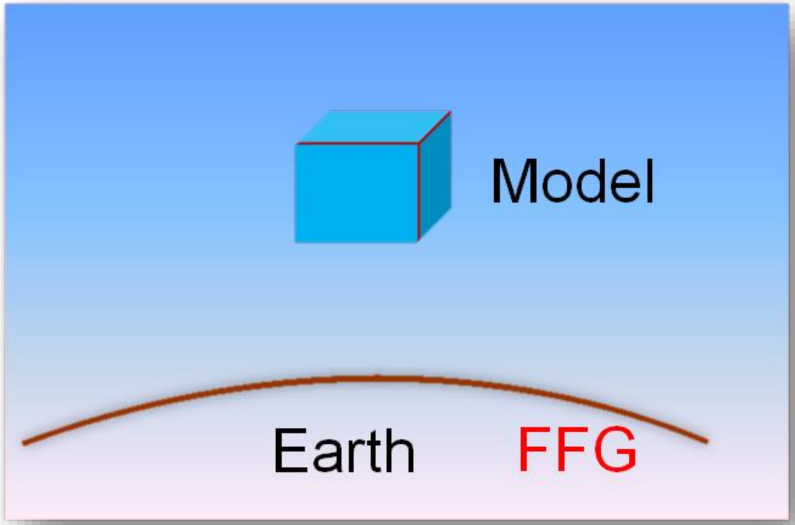
- FFG = Far field ground - always present in model
- NFG = Near field ground - added by user if needed





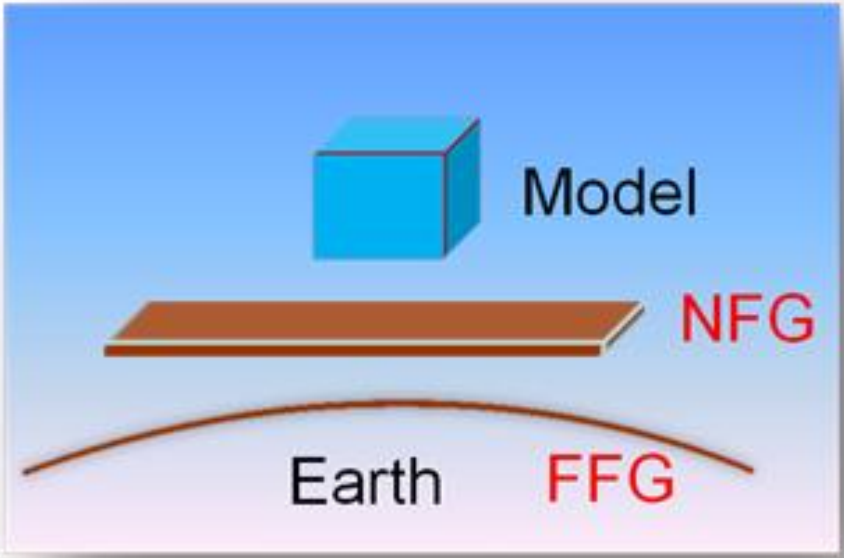
FFG – Far Field Ground Model

- Always present in Patran ESM models
- The ground is far enough away that ground-shadowing effects are unimportant
- If the FFG surface temperature is not directly specified by the user, the FFG is modeled and surface temperature computed automatically as part of the analysis process
- FFG is modeled in 1D as a series of user-described layers, each with its own thickness and material properties
- In Thermica, the FFG is “the planet”



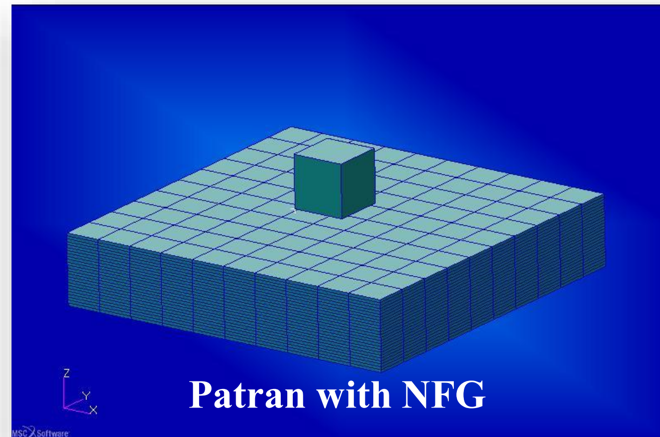
NFG – Near Field Ground Model

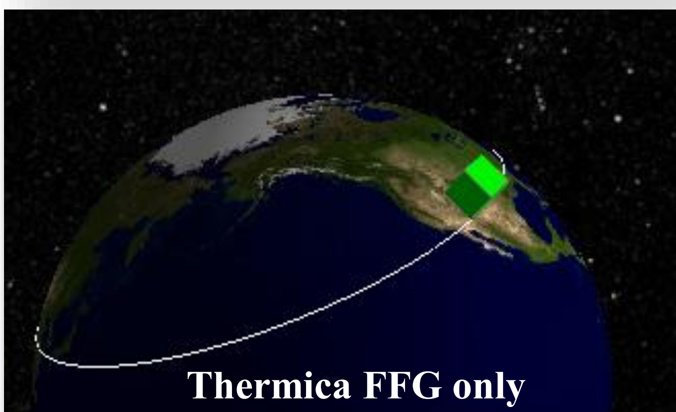
- NFG model is optional and only present if user geometrically models it. It is In addition to the FFG which is always present
- NFG Model Is a 3D slab of ground with one or more layers – typically about 2 meters deep.
  - Bottom of the NFG model is usually set to the deep ground temperature from the EPW data. Yearly variations of the deep ground temperatures is small enough and has little affect on the surface temperature so can just use a constant value.
  - Model can be embedded into the ground if desired
- Typically NFG and FFG layers and surface boundary conditions are the same, but this is not required

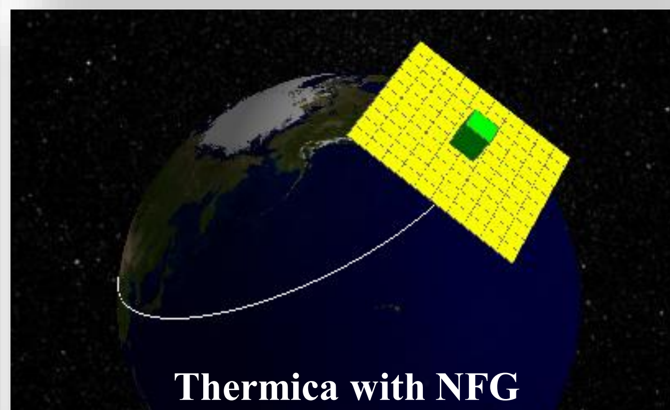


Patran Models with and without a NFG Model

The FFG (i.e. the planet) is always present

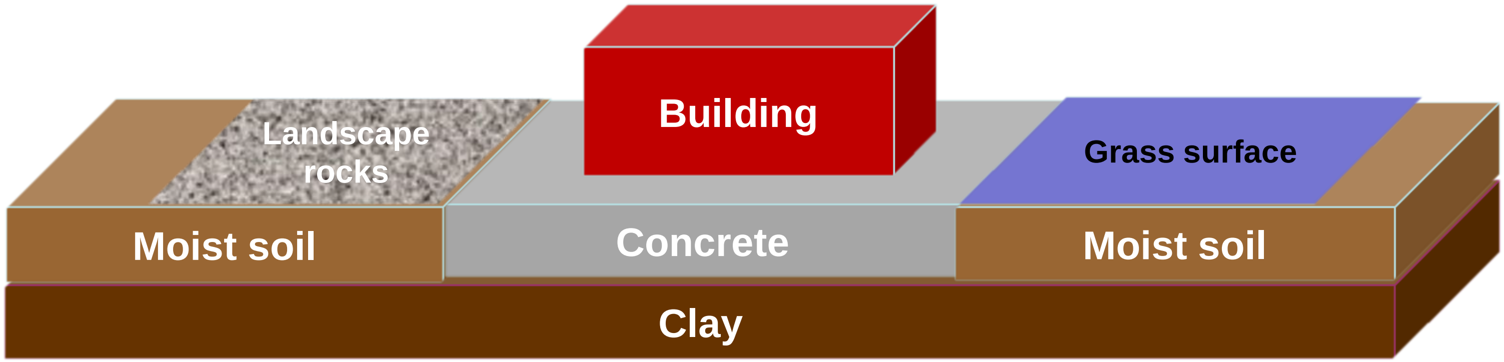






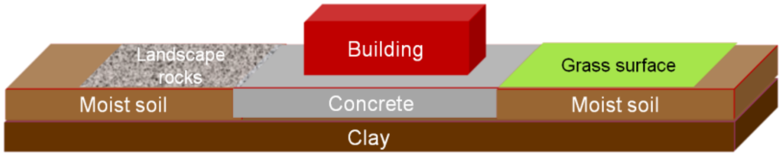
Affects of a NFG Model

- NFG modeling accounts for shadows cast on the ground by the model and spatial varying surface properties which may cause the following:
  - Temperature variations along the surface
  - Ground-reflected solar radiation variations

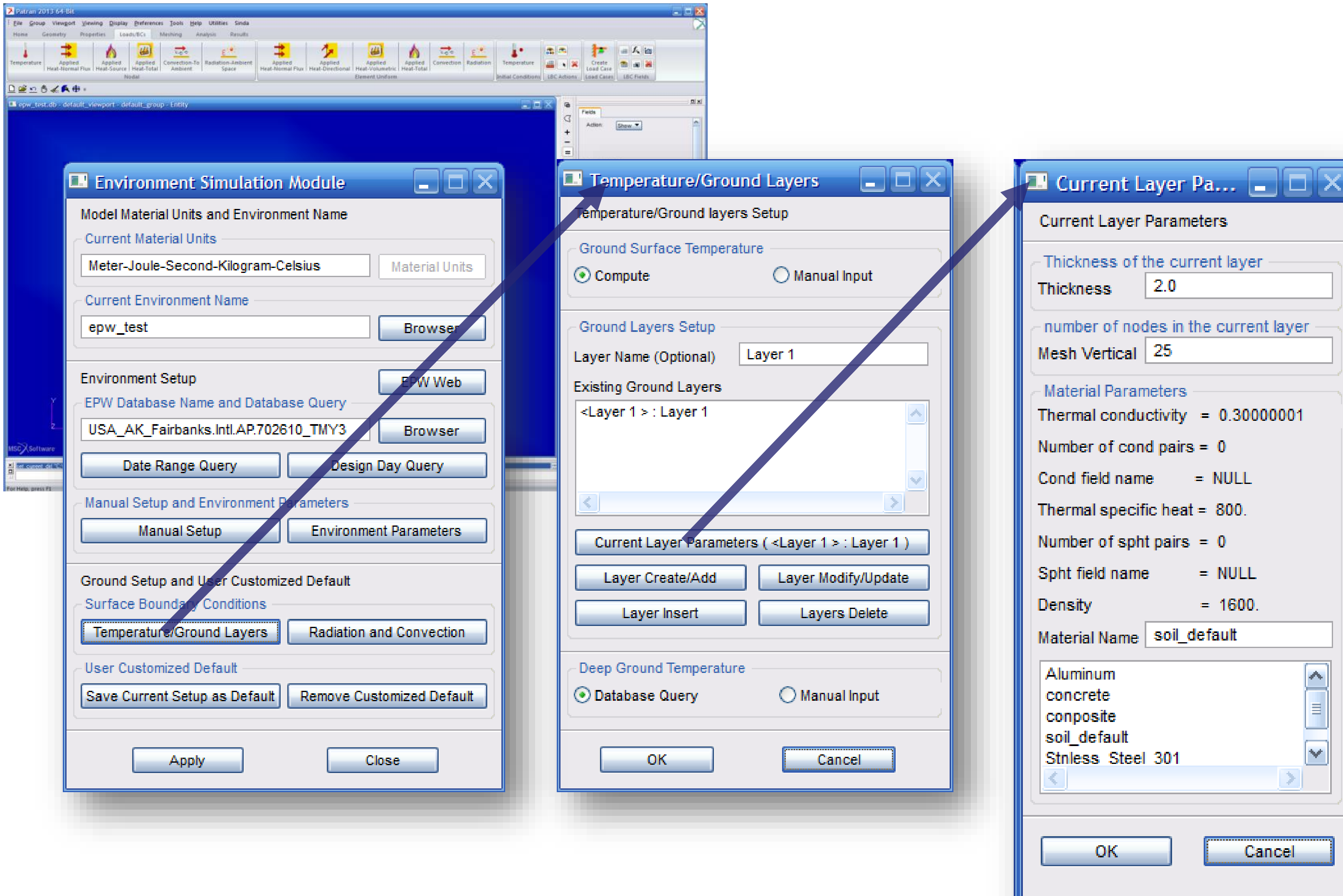


When is it Important to Add a NFG Model

- When a NFG model is needed
  - Model is close enough to the ground for shadowing effects or non uniformity of the ground model become important
  - Model is embedded in the ground
- When you can ignore a NFG model
  - Spatially uniform ground temperature and reflected solar radiation is an acceptable assumption
  - NOTE: the bottom of the model will be illuminated from below by ground reflected solar radiation (albedo), even if Z=0.0!
  - MODELING TRICK: If model is flat-bottom, low absorptivity value on bottom prevent albedo from below, but more complex shapes may require modeling the NFG
- Conclusions
  - The NFG is often not needed
  - Even if ultimately used in the model your first model should exclude it
    - To help understand the relative importance of ground shadowing to the final answers.
    - To evaluate if the NFG computation burden is justified by the change in results, to be judged case by case

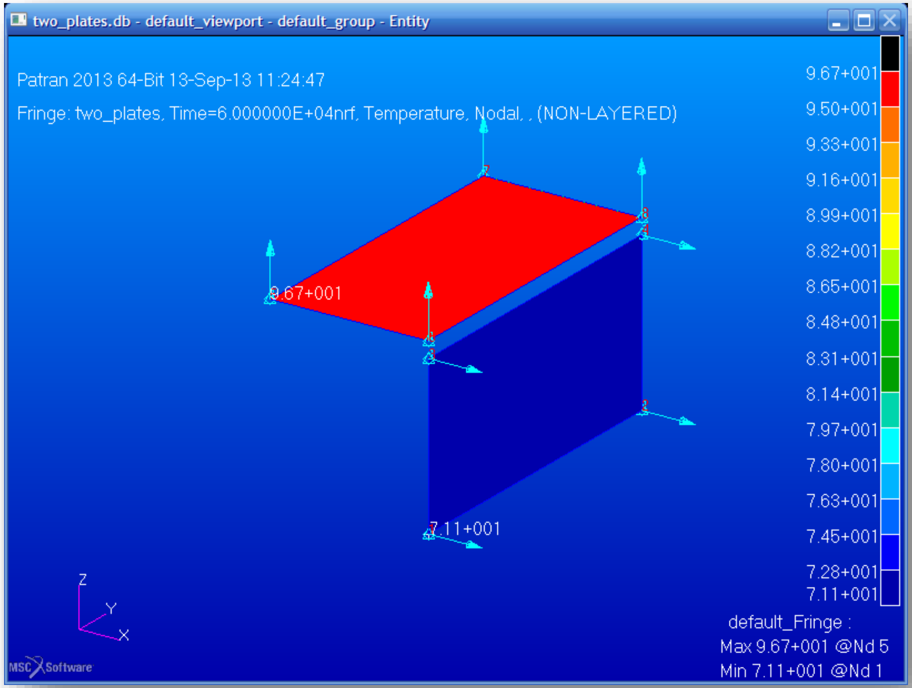


FFG Model Setup in the Patran ESM

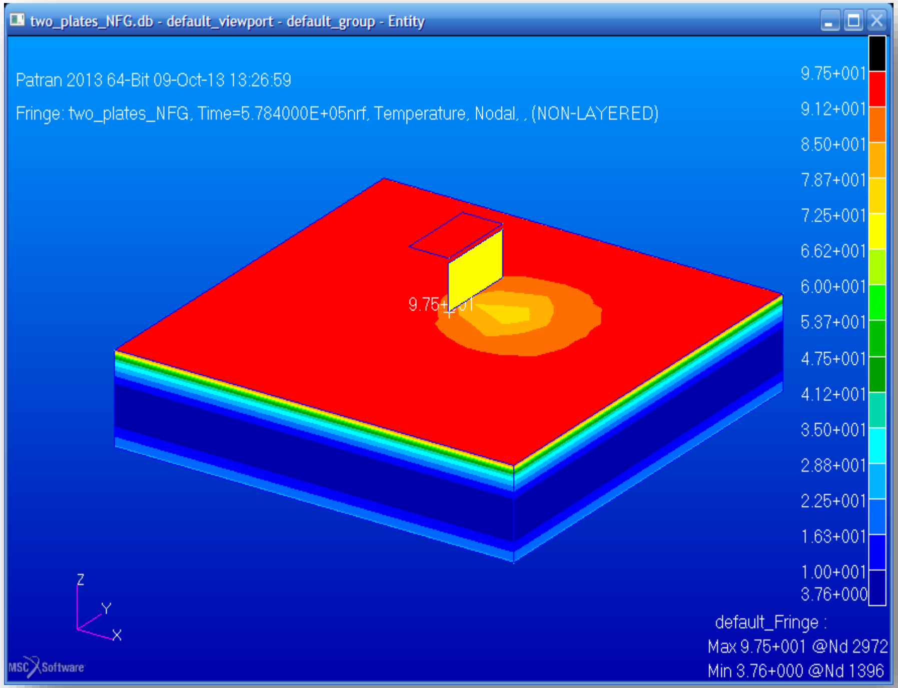


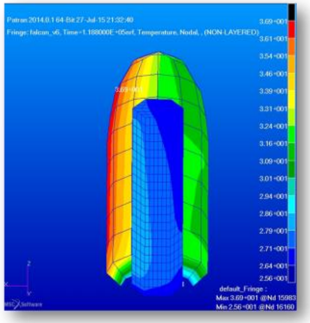
Examples With and Without a NFG Model

No local ground model



With local ground model



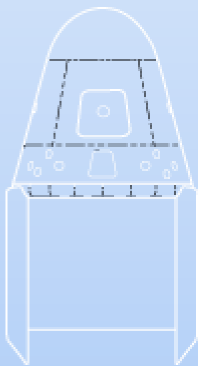


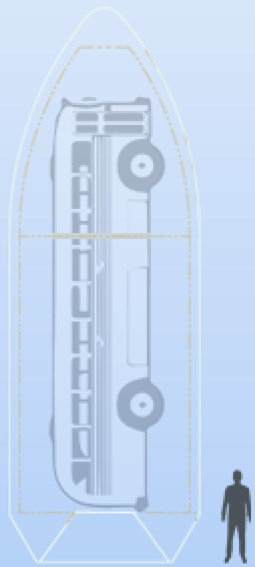
Example Model

Model of Falcon 9 rocket on a launch pad is used to show the analysis process.

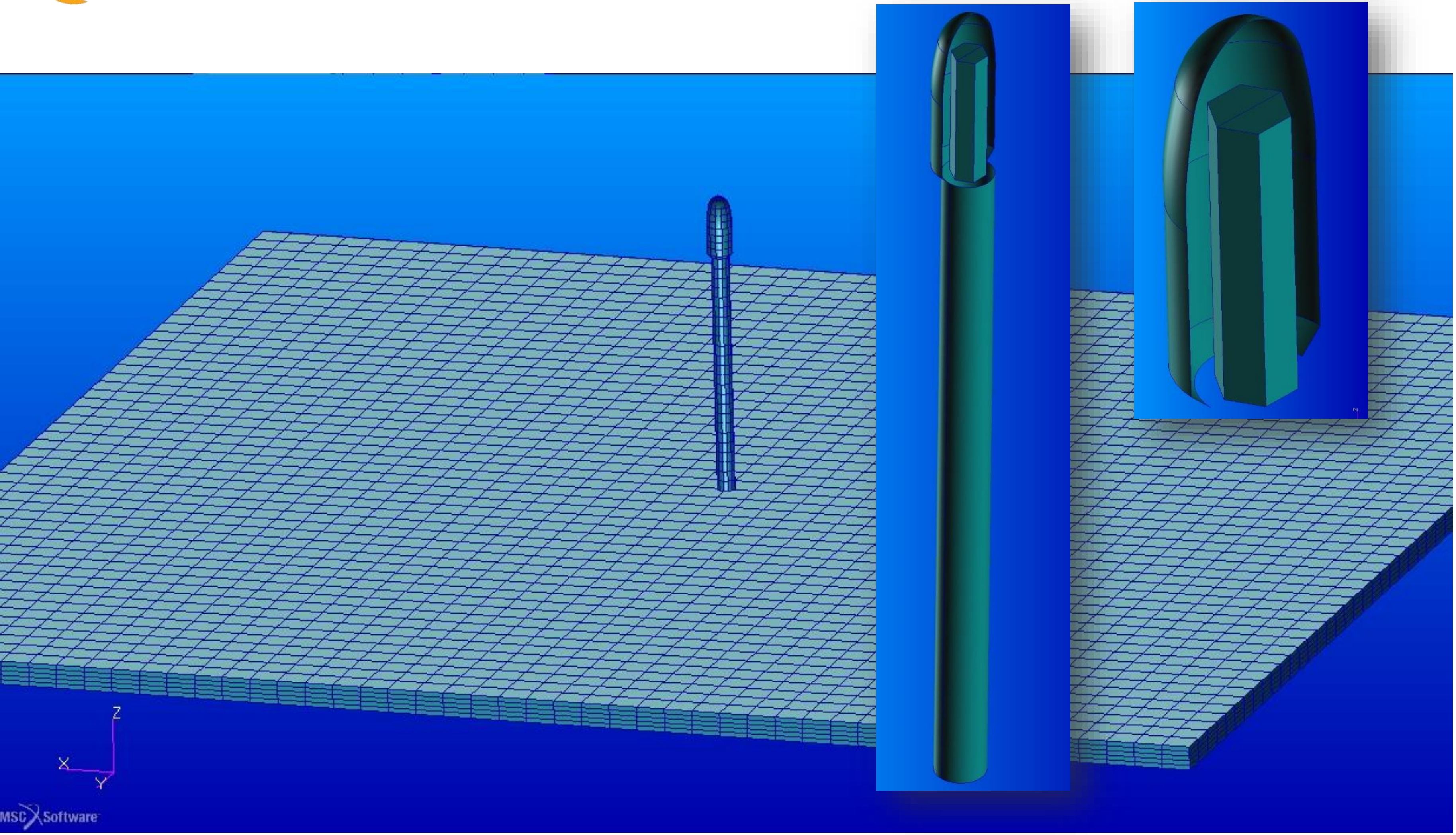
Note: This model is simplified and does not represents actual hardware

Example Model



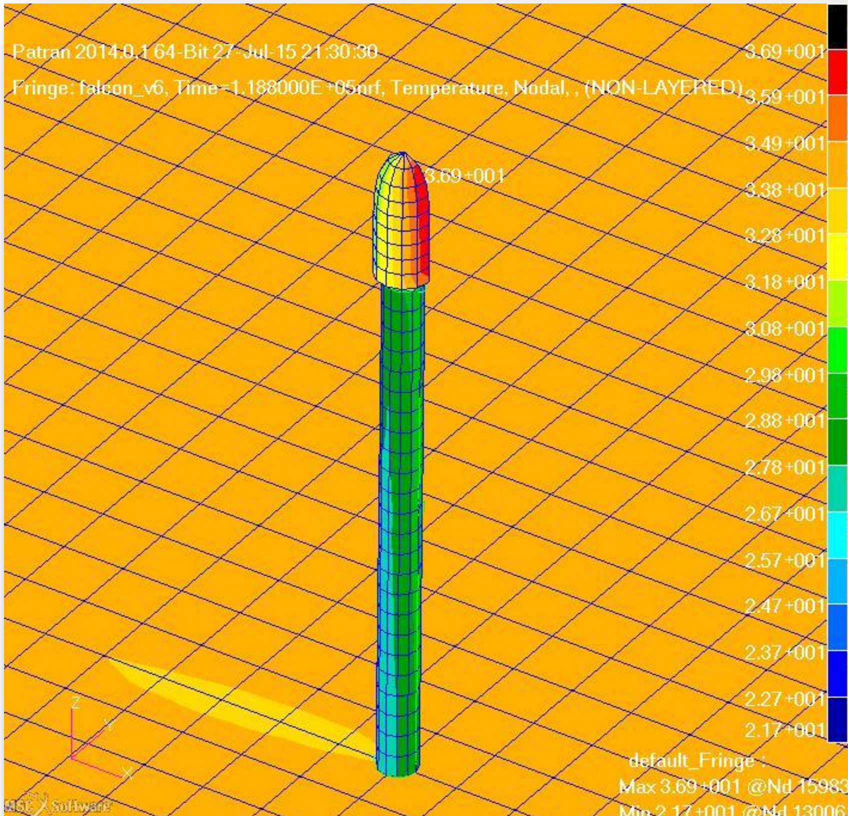


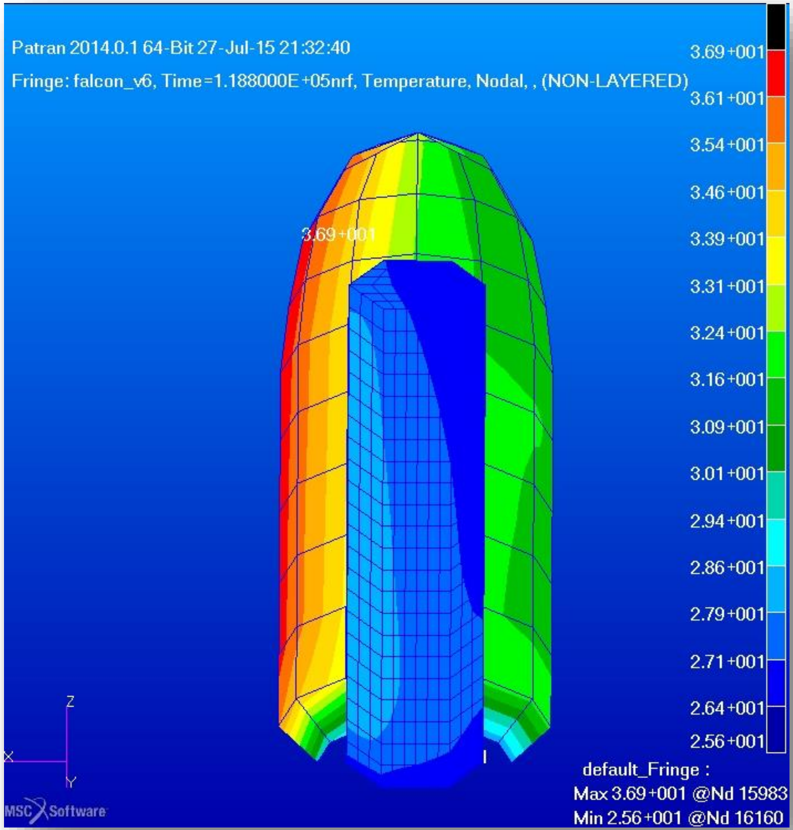
Patran Model



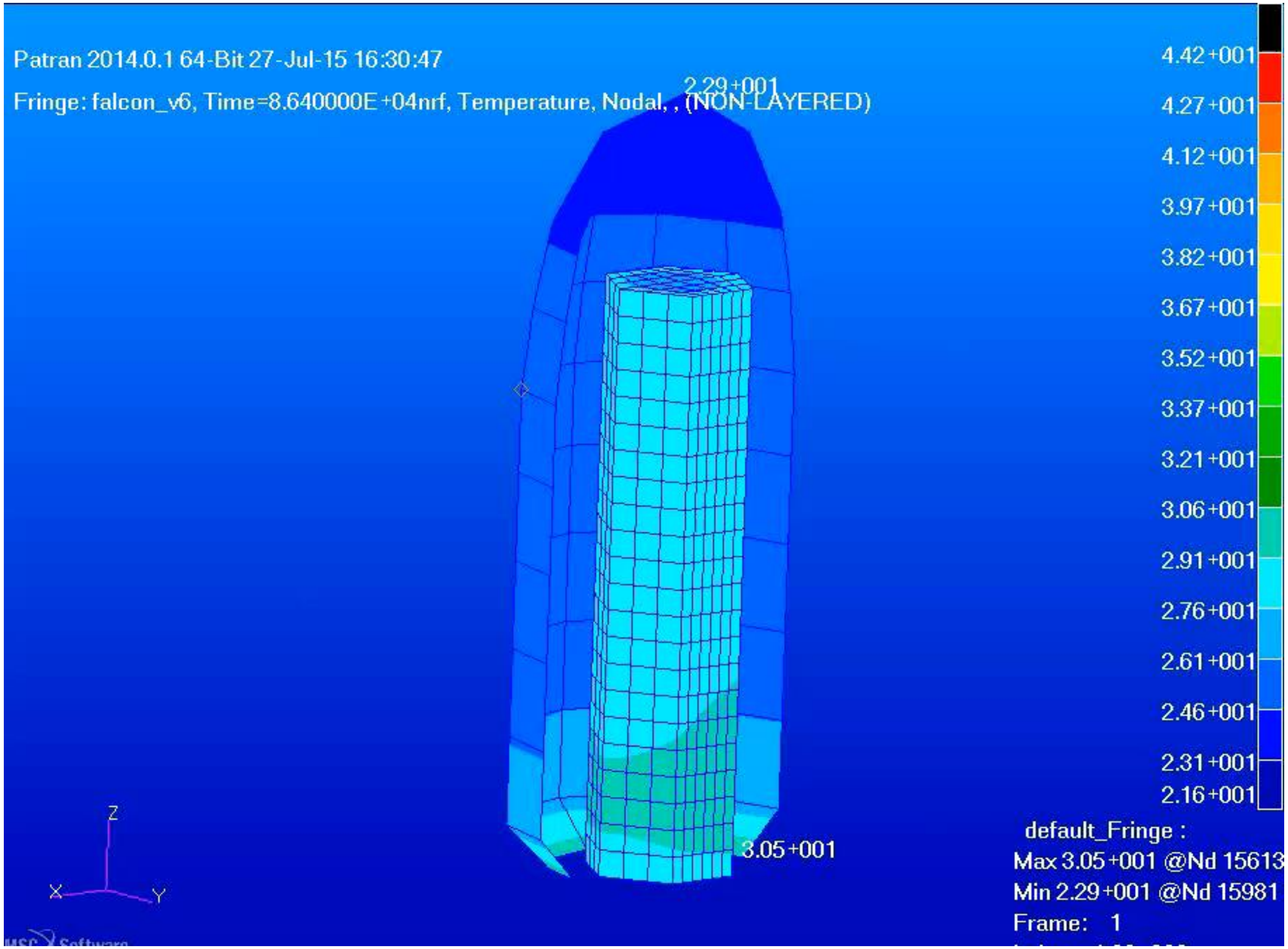
Simplified model was build to illustrate the method and did not use realistic materials

Temperature Results





Temperature for 24 Hours Starting at 12:00AM



Summary

- EPW files with typical meteorological year data is useful for realistic thermal modeling of aerospace hardware in the sun. Other data can also be extracted or computed such as air temperature, wind speed, sky temperature and deep ground temperature.
- Mil Spec's maybe be required, but may create unrealistic results. Engineers can add reliability and confidence to their designs using EPW data.
- These techniques can be used with any full featured thermal analysis software, but require manual setup.
- MSC's Environment Simulation Model makes it easy to utilize this data and also allow creation of worst hot/cold cases to be computed from the data